REMARKS

This Preliminary Amendment cancels, without prejudice, claims 1 to 17 in the underlying PCT Application No. PCT/EP2004/008483 and adds new claims 18 to 34. The new claims, inter alia, conform the claims to United States Patent and Trademark Office rules and does not add any new matter to the application.

In accordance with 37 C.F.R. § 1.125(b), the Substitute Specification (including the Abstract) contains no new matter. The amendments reflected in the Substitute Specification (including Abstract) are to conform the Specification and Abstract to United States Patent and Trademark Office rules or to correct informalities. As required by 37 C.F.R. §§ 1.121(b)(3)(ii) and 1.125(c), a Marked-Up Version of the Substitute Specification comparing the Specification of record and the Substitute Specification also accompanies this Preliminary Amendment. Approval and entry of the Substitute Specification (including Abstract) are respectfully requested.

The underlying PCT Application No. PCT/EP2004/008483 includes an International Search Report, dated March 16, 2005, a copy of which is included. The Search Report includes a list of documents that were considered by the Examiner in the underlying PCT application.

It is respectfully submitted that the subject matter of the present application is new, non-obvious and useful. Prompt consideration and allowance of the application are respectfully requested.

Respectfully submitted,

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SCANNING HEAD FOR OPTICAL POSITION-MEASURING SYSTEMS

FIELD OF THE INVENTION

The present invention relates to a scanning head for optical position-measuring systems. Such scanning heads are used to detect light modulated by a scale grating in a spatially resolved manner and to make available corresponding signals for the purpose of determining the position of the scanning head relative to the scale.

BACKGROUND INFORMATION

Position-measuring systems play an ever more important role in this increasingly automated world. They furnish the basis for exact positioning of drive systems in many applications, for ~~instance~~ **example**, in the field of machine tools. The optical position-measuring systems described ~~here~~ **herein** are based on scanning a scale that has a measuring standard in the form of a line grating. The scanning head used for this includes a light source from which light falls on the scale graduation via a transmitting grating. After the interaction with the transmitting grating and the scale grating, the light has a spatial intensity pattern which is able to be detected in the scanning head using a receiving grating and is able to be used for position determination.

~~On this point, it~~ **It** is ~~known that one may~~ **conventional to** form a photodetector from a plurality of photosensitive areas. These photosensitive areas are ~~situated~~ **arranged** in the scanning head ~~in~~ such ~~a way~~ that they are able to record the different phases of the intensity pattern and to supply corresponding electrical output signals. The individual, evenly spaced photosensitive areas form a receiving grating, in this context.

~~Preferably, four~~ **Four** signals ~~are~~ **may be** generated that are offset by 90 degrees with respect to each other in each case, from which, in a sequential electronic system, counting signals connoted with direction may be derived. ~~For, in~~ **In** response to the shifting of the scale relative to the scanning head, the individual phase-shifted signals change as a function of position.

Usually, from the four output signals mentioned, first of all two signals shifted by 90 degrees with respect to each other and free from offset errors, amplitude errors and phase errors are synthesized, which are suitable for a finer subdivision and interpolation. The counting signals connoted with direction are able to permit therewith a substantially finer position determination than would be possible, for example, by counting the maxima and/or minima of the intensity pattern at the photosensitive areas of the scanning head.

For reasons described further on, it ~~is advantageous if~~ **may be provided that** the individual photosensitive areas are as near as possible to one another. The use of discrete component parts, such as photodiodes, limits~~, in this case,~~ the possible miniaturization of the photodetectors. Therefore, structured photodetectors have been implemented which, using ~~customary~~ **conventional** process steps of microelectronics, permit the production of structured, photosensitive areas on one single semiconductor substrate.

Because of the low inclination to cross feed between the individual photosensitive areas, in this context, there is available, above all, the technologically well manageable amorphous silicon (a-Si), whose use for converting light to electric current is ~~known~~ **conventional**, for ~~instance~~ **example**, ~~from~~ **in** the solar cell field.

~~DE 10129334 A1~~ **German Published Patent Application No. 101 29 334** describes an optical position-measuring system having a light-receiving device based on the principle described above. The photosensitive areas for scanning of locally intensity-modulated light of different phase positions are constructed as receiving gratings in the form of several semiconductor layer stacks of doped and undoped amorphous silicon. The construction of the structured detectors is very complex, however, so that the method for its production is also costly.

SUMMARY

~~It is the object~~ **Example embodiments** of the present invention ~~to create~~ **may provide** a simplified scanning head, compared to the ~~related art~~ **conventional devices**, for an optical position-measuring device that supplies signals that are as good as possible for position determination.

~~This object is attained by a device having the features of Claim 1. Advantageous specific embodiments are derived from the features delineated in the claims dependent on Claim 1.~~

A scanning head is described for an optical position-measuring system having a receiving grating formed of photosensitive areas, for scanning locally intensity-modulated light of different phase positions. The receiving grating is formed from a semiconductor layer stack, made up of a doped p-layer, an intrinsic i-layer and a doped n-layer. The individual photosensitive areas have a first doped layer and at least one part of the intrinsic layer in common, and are separated electrically from one another by interruptions in the second doped layer.

~~For, it was~~ **It is** understood~~, on the one hand,~~ that even the separation of only one of the doped layers ~~leads~~ **may lead** to a

sufficient electrical separation of the individual photosensitive areas. A cross feed, that is a disadvantage for the purposes of position determination, between areas of a different phase position does not appear any more, even at very slight distances of the individual areas with respect to one another.

On the other hand, such a layer construction also avoids another problem ~~described in the related art~~ **associated with conventional device**. ~~For, if~~ **If** the photosensitive areas are separated also by separating the intrinsic layer (and possibly also the second doped layer), deep trenches are formed which are managed only with difficulty in etching technology. Etching defects in the region of the intrinsic layer are also able to effect defects in the semiconductor material, whereby the photoelectric properties of the individual photosensitive areas are influenced in a very negative manner.

Amorphous silicon ~~is~~ **may be** particularly suitable as semiconductor material, but semiconductor layer stacks are also ~~conceivable~~ **possible** which totally or partly ~~contain~~ **include** microcrystalline silicon.

Additional features, such as the positioning of the transmitting grating in the center of area of the receiving grating, an approximately elliptical or oval shape of the receiving grating, which has a greater extension perpendicular to the measuring direction than parallel to it, as well as the obtaining of phase-shifted signals from, in each case, a single period of the modulated light at the receiving grating lead to an optimization of the obtained scanning signals, and thus to an improved interpolation capability, and thus, ~~finally~~ to a higher resolution of the optical position-measuring system.

The ~~design~~ **arrangement** of the scanning head, and ~~especially~~ **, e.g.,** of the receiving grating with its photosensitive areas, permits in an elegant manner such optimizations in the layout of the structured detectors.

According to an example embodiment of the present invention, a scanning head for an optical position-measuring system includes a receiving grating including photosensitive areas adapted to scan locally intensity-modulated light of different phase position, the receiving grating including a semiconductor layer stack that includes a doped p layer, an intrinsic i layer and a doped n layer. The photosensitive areas have in common a first of the two doped layers and at least a part of the intrinsic layer and are electrically separated from one another by interruptions of a second of the two doped layers.

Further ~~advantages~~ **aspects of example embodiments** of the present invention and details pertaining thereto are ~~derived from~~ **explained in more detail below in** the following description ~~of preferred specific embodiments, on the basis of the figures. In this context, the figures show:~~ **with reference to the appended Figures.**

BRIEF DESCRIPTION OF THE DRAWINGS

Figures ~~1 a/b/c~~ **1a to 1c illustrate** an optical position-measuring unit[[,]]**.**

Figures ~~2a/b/c/d/e~~ **2a to 2e illustrate example** embodiments of a dual field sensor~~, and~~**.**

Figures ~~3a/b/c/d~~ **3a to 3d illustrate example** embodiments of a single field sensor.

DETAILED DESCRIPTION

Figure 1a ~~shows~~ **illustrates** a scale 2, which carries an optical grating on a substrate 2.1, which is ~~here~~ also to be designated as scale graduation 2.2. Such a scale graduation 2.2 is able to exist, for example, as an amplitude grating having opaque crosspieces made of chromium and light transmitting gaps in the chromium coating. In this context, substrate 2.1 may be developed to be light-transmitting or, as ~~in the case shown~~ **illustrated**, reflecting. Other scales 2 are also able to have a phase grating or a combination of phase grating and amplitude grating.

Positioned opposite to the scale is a scanning head 1. scanning head 1 includes a light source 1.6, whose light falls, via a transmitting grating 1.5, on scale 2, is reflected there and redirected to scanning head 1. After the interaction with transmitting grating 1.5 and scale grating 2.2, the light has a local intensity pattern having a regular period. This intensity pattern is detected using a receiving grating 1.7 having a scale division T. In this context, receiving grating 1.7 itself is used as a patterned photodetector for detecting the intensity pattern.

~~For, receiving~~ **Receiving** grating 1.7 has a patterned semiconductor layer stack 1.2 which converts incident light to electric current. In this context, the more current that is generated, the more the light that falls on semiconductor layer stack 1.2.

Figure 1b ~~shows~~ **illustrates** an enlarged section of Figure 1a. One may see substrate 1.1, on which a transparent electrode 1.3 is ~~situated~~ **arranged** which, in turn, carries semiconductor layer stack 1.2. In the sequence of the passage of the light, the latter has a first doped (p-doped, in this case) layer 1.2.1 (p-layer), then an intrinsic layer 1.2.2 (i-layer), and

~~finally~~ a second doped (n-doped, in this case) layer 1.2.3 (n-layer). An electrical bottom contact follows n-layer 1.2.3. In principle, p-layer 1.2.1 and the n-layer ~~could~~ **may** be exchanged, but the construction ~~shown~~ **illustrated** in Figure 1b ~~is~~ **may be** preferred.

The photosensitive areas forming receiving grating 1.7 are separated from one another in that n-layer 1.2.3 having bottom contacts 1.4 are interrupted where a separation of the individual photosensitive areas for detecting the intensity pattern are provided. Only in the region of bottom contacts 1.4 is current generated in semiconductor layer stack 1.2 in response to illumination, and so bottom contacting 1.4 defines receiving grating 1.7.

As ~~may be seen~~ **illustrated** in Figure 1b, the patterning of bottom contacting 1.4 and n-layer 1.2.3 is able to take place in a single lithography step and an etching step each for bottom contacts 1.4 and semiconductor layer stack 1.2. As the etching method for semiconductor layer stack 1.2, wet etching methods (e.g.**,** KOH solution)~~, but preferably~~ **or** dry etching methods (e.g.**,** RIE using CHF_3) ~~come into consideration~~ **may be used**. Such methods are widespread in microelectronics~~, and are therefore available without any problem~~.

Figure 1c, another section enlargement of Figure 1b, ~~shows~~ **illustrates** a detail of semiconductor layer stack 1.2. In order to be sure that n-layer 1.2.3 is completely interrupted (~~this is an absolutely necessary requirement~~ **e.g.**, in order to separate the individual photosensitive areas), it ~~is~~ **may be** necessary to set the etching process ~~in~~ such ~~a way~~ that at least a small part of i-layer 1.2.2 is also removed. On the other hand, at least a small part of i-layer 1.2.2 ~~must be left standing~~ **should remain**, in order to be certain to prevent

an electrical connection between p-layer 1.2.1 and n-layer 1.2.3

The layer construction in the region of receiving grating 1.7 ~~could~~ **may** also ~~look~~ **be arranged** as follows: A layer of ZnO:Al of 0.3 [[-]] **to** 1 μm thickness is applied to a glass substrate 1.1 of ~~ca.~~ **approximately** 1 millimeter thickness, ~~which is~~ **the ZnO:Al layer being** well suited to be transparent electrode 1.3. There follows semiconductor layer stack 1.2 having a p-layer 1.2.1 of ~~ca.~~ **approximately** 10 nm, an i-layer 1.2.2 of ~~ca.~~ **approximately** 400 nm, and an n-layer 1.2.3 of ~~ca.~~ **approximately** 20 nm thickness. Bottom contacts 1.4 are made up of a metallic layer of ~~a ca.~~ **approximately** 80 nm thickness, for ~~instance~~ **example**, of chromium or aluminum. This metallic layer, in common with n-layer 1.2.3, is completely removed at suitable places for separating the individual photosensitive areas.

Because of the etching process used for separating the photosensitive areas, i-layer 1.2.2 is also taken down by ~~ca.~~ **approximately** 40 nm, in order to achieve as certain a separation of n-layers 1.2.3 as possible. This ~~is~~ **may be** necessary, since the individual layers are not completely homogeneous with respect to their thickness, and besides, there is no sharply limited transition in the doping profile of semiconductor layer stack 1.2, especially between i-layer 1.2.2 and n-layer 1.2.3. In this connection, it is to be expected that, between photosensitive areas 3, a residual thickness of ~~5%-95%~~ **5% to 95%**, ~~better 10%-90%~~ **e.g., 10% to 90%,** of the original thickness of i-layer 1.2.2 leads to good results. From a manufacturing technology point of view, since shorter etching times are to be preferred, and at greater residual thicknesses of i-layer 1.2.2 problems dealing with defects at the laid-bare edge of i-layer 1.2.2 ~~are~~ **may be** avoided, then, in the ranges stated, the upper boundaries

(that is, ~~ca.~~ **approximately** 95% or ~~ca~~ **approximately** 90%) ~~are to~~ **may** be preferred. For the named layer thickness of 400 nm within photosensitive areas 3, a residual thickness of ~~ca.~~ **approximately** 360 nm for i-layer 1.2.2 ~~is~~ **may** thus **be** regarded as being optimal.

~~Let us have a look now~~ **It is considered below** at what distance apart the individual photosensitive areas have to be positioned in order to receive the desired phase-shifted signals. This distance corresponds to scale division T of receiving grating 1.7. Let the period of the intensity pattern of the light irradiating receiving grating 1.7 be P. In scanning heads 1 having photosensitive areas ~~developed~~ **arranged** as receiving grating 1.7, because of the danger of cross feed between the photosensitive areas, scale division T has to be selected to be greater than period P. If four signals phase-shifted by 90 degrees are desired, the following ~~must apply~~ **applies**

$T = (2 * n - 1) * 1/4 * P$ (n is an integer greater than or equal to three).

For a period $P = 40$ µm of the intensity pattern of the irradiated light, there thus comes about a scale division T of at least 50 µm. The individual phase-shifted signals are therefore gathered from four different periods of the intensity pattern, and thus also from different ranges of scale graduation 2.2. Therefore, ~~let us designate~~ this type of patterned detector **is designated** as a four field sensor. It ~~has~~ **may have** the disadvantage that contamination on the scale take effect on phase-shifted signals not at the same time, but offset in phase. This ~~results~~ **may result** in inaccuracies during the evaluation of the phase-shifted signals.

Therefore, it is **considered** better to scan phase-shifted signals within a period P of the intensity pattern at receiving grating 1.7. One possibility for this is represented by the dual field sensor, ~~shown~~ **illustrated** in Figures ~~2a-2e~~ **2a to 2e**.

Photosensitive areas 3 are schematically ~~seen~~ **illustrated** in Figure 2a, whose design has already been shown in detail in Figures ~~1a-1e~~ **1a to 1c**. These photosensitive areas are ~~situated~~ **arranged** on substrate 1.1. Intensity pattern L having period P is schematically ~~shown~~ **illustrated**, and so is measuring direction M. One may see that, now within one period P, both a 0 degree signal and a 180 degree signal is able to be picked off. Adjacent photosensitive areas supply 180 degree phase-shifted signals if scale division T of receiving grating 1.7 corresponds to one-half of period P of incident, locally modulated intensity pattern L.

The following applies:

T= 1/2 * P.

Consequently, contamination on scale 2 will have an effect on both phase-shifted signals.

Figure 2b ~~shows~~ **illustrates** how photosensitive areas 3 are able to be connected to one another by printed conductors 4, in order to combine several 0 degree signals and several 180 degree signals to a stronger output signal. In this context, a comb structure is created in each case. These comb structures intermesh, so that in each case photosensitive areas 3 for 0 degree signals and photosensitive areas 3 for 180 degree signals alternate. As ~~may be seen~~ **illustrated** in Figure 2b, such a structure may be produced without crossed-over printed conductors.

Figure 2c ~~shows~~ **illustrates** how, using four comb structures, of which in each case two are interleaved according to Figure 2b, four signals may be gathered that are phase-shifted by 90 degrees in each case. However, since two different ranges of the intensity pattern are scanned at receiving grating 1.7, ~~one would call~~ this **is referred to as** a dual field sensor.

Figure 2d ~~shows~~ **illustrates** an ~~especially advantageous design~~ **arrangement** of such a scanning head 1 having a dual field sensor. Transmitting grating 1.5 is ~~situated~~ **arranged** at the center of the dual field sensor. By "center", the center of area of receiving grating 1.7 ~~is to~~ **should** be understood. Quadratic transmitting grating 1.5, in this context, is completely surrounded by receiving grating 1.7, in order to utilize as well as possible intensity pattern L. The grating lines of transmitting grating 1.5 and receiving grating 1.7 are perpendicular to measuring direction M. Receiving grating 1.4 is subdivided into four areas. Of the two inner areas, which border directly on transmitting grating 1.5, one is used for gathering 0 degree/180 degree signals, and the other of the two for gathering 90 degree/270 degree signals. An additional 90 degree/270 degree area, facing away from transmitting grating 1.5, borders on the inner 0 degree/180 degree area. An additional 0 degree/180 degree area, facing away from transmitting grating 1.5, borders on the inner 90 degree/270 degree area. This arrangement antisymmetric to the measuring direction makes certain that the four phase-shifted signals are picked up at comparable intensities.

The outer shape of entire receiving grating 1.7, that is composed of the four areas mentioned, as a rectangle having beveled corners, is approximated to an oval or an ellipse, whose greater diameter is perpendicular to measuring direction

M. Such a shape ~~permits~~ **may permit** an especially good utilization of intensity pattern L at receiving grating 1.7.

The four different areas of receiving grating 1.7 ~~according to~~ **illustrated in** Figure 2d are constructed by interleaved comb structures according to Figure 2c. A cutout enlargement of Figure 2d in Figure 2e makes this clear. This dual field sensor, which ~~has proven~~ **may be** very suitable in practice, may also therefore be produced without crossed-over printed conductors, which keeps the production process simple: Only one single metallization plane is required. With their patterning, photosensitive areas 3 are specified at the same time.

The dual field sensor described ~~has the advantage~~ **may provide** that the amplitudes of the 0 degree/180 degree signals and the amplitudes of the 90 degree/270 degree signals are affected by possible contaminations simultaneously, and therewith in-phase. This ~~reduces~~ **may reduce** the scanning ratio error and ~~increases~~ **may increase** the accuracy of the position determination as compared to a four field sensor. However, it is not the case, that all amplitudes of the four phase-shifted signals are impaired in-phase by contamination, so that the scanning is able to be further improved.

~~One obtains further~~ **Further** improved signals **may be obtained** from a scanning head 1 denoted here as a single field sensor. It is ~~shown~~ **illustrated** in Figure 3a that, in such a single field sensor, in each case four phase-shifted signals are obtained from one single period P of intensity pattern L. Adjacent photosensitive areas supply 90 degree phase-shifted signals if scale division T of receiving grating 1.7 corresponds to one-quarter of period P of incident, locally modulated intensity pattern L. The following equation applies:

T= 1/4 * P.

From the view in Figure 3b ~~one may see~~ **it is illustrated** that such a single field sensor ~~can~~ **may** no longer do without crossed-over printed conductors. ~~For, photosensitive~~ **Photosensitive** areas 3 do carry a bottom contact 1.4 on their reverse side, which is allowed to be connected to the printed conductors only at certain locations, using contactings 5. Between photosensitive areas 3 and printed conductors 4, an insulating layer thus has to be brought in which is only interrupted at contactings 5. Contacting 5 is simply formed by printed conductors 4 coming into contact directly with bottom contacts 1.4, when the metal layer forming printed conductors 4 is deposited.

~~It has been shown that, for~~ **For** a semiconductor layer stack 1.2 having the ~~design~~ **arrangement** described herein, a separation distance A of 5 μm ~~is certainly~~ **should be** sufficient to avoid cross feed between the individual photosensitive areas 3. However, depending on the detector geometry and the semiconductor material, even shorter distances A in the μm range ~~are able to~~ **may** lead to functional scanning heads 1. The minimum distance A is ~~essentially~~ **substantially** determined by the diffusion length of the charge carrier in i-layer 1.2.2. The shorter this diffusion length is, the shorter ~~can~~ **may** distance A be. ~~If we assume~~ **Assuming** a diffusion length of 50 nm for amorphous silicon, then no more cross feed should occur at a distance A of ~~ca.~~ **approximately** 200 nm. However, since for technical process reasons (increasing expenditure and rising sensitivity to defects for smaller structures) greater distances A ~~are to~~ **may** be preferred, it may be stated that a meaningful lower boundary for distance A ~~would~~ be ~~ca.~~ **may be approximately** 1 μm.

For a period P = 40 µm of the intensity-modulated light, for the four field sensor there comes about a scale division T of receiving grating 1.7 of 10 µm. Thus, at a distance A = 5 µm, photosensitive areas 3 themselves are down to only 5 µm.

Figure 3c ~~shows a specific~~ **illustrates an example** embodiment of such a single field sensor. Again, a transmitting grating 1.5 is ~~situated~~ **arranged** in the center, or rather center of area, of receiving grating 1.7.. Receiving grating 1.7, whose line direction, same as that of transmitting grating 1.5, again ~~runs~~ **extends** perpendicular to measuring direction M, has an outer shape approximating an ellipse, whose greater diameter is perpendicular to measuring direction M. ~~In the same way as in~~ **Similar to** Figure 3b, receiving grating 1.7 is connected to printed conductors 4 that ~~lie~~ **are** transversely across receiving grating 1.7. Respectively four such printed conductors 4 are ~~situated~~ **arranged** on both sides of transmitting grating 1.5, so that they are also able to contact completely photosensitive areas 3 that are interrupted by transmitting grating 1.5.

Figure 3d ~~shows one variant~~ **illustrates an arrangement** of the contacting of photosensitive areas 3 that is to be recommended as an alternative, and especially so for small scale divisions T of receiving grating 1.7 of the single field sensor. At the edge of receiving grating 1.7, grating lines having enlargements are provided. Since every other grating line is lengthened, it is possible to make these enlargements twice as wide as the grating lines themselves. This **may** greatly ~~simplifies~~ **simplify** the contacting of photosensitive areas 3 with printed conductors 4 via contactings 5. Again, it may be seen that such a single field sensor cannot be produced without crossover printed conductors 4.

It should still be mentioned that transmitting grating 1.5 ~~preferably has~~ **may have** the same layer construction as photosensitive areas 3. Since edges that are as sharply defined as possible are desirable for transmitting grating 1.5, semiconductor layer stack 1.2 is completely etched through in this region. However, it is also possible to develop transmitting grating 1.5 only as a patterned metal layer directly on substrate 1.1~~, in the usual manner~~. In both cases, it is possible to perform the patterning of transmitting grating 1.5 and photosensitive areas 3 using the same lithography step.

~~Abstract~~

ABSTRACT

A scanning head for an optical position-measuring system ~~is disclosed, comprising~~ **includes** a receiver grating ~~(1.7)~~, formed of photosensitive areas ~~(3)~~, for the scanning of locally intensity-modulated light of differing wavelengths. The receiver grating ~~(1.7)~~ is formed from a semiconductor layer stack ~~(1.2)~~ of a doped p-layer ~~(1.2.1)~~, an intrinsic i-layer ~~(1.2.2)~~ and a doped n-layer ~~(1.2.3)~~. The individual photosensitive areas ~~(3)~~ have a first doped layer ~~(1.2.1)~~ and at least a part of the intrinsic layer ~~(1.2.2)~~ in common and are electrically separated from one another by ~~means of~~ interruptions in the second doped layer ~~(1.2.3)~~.